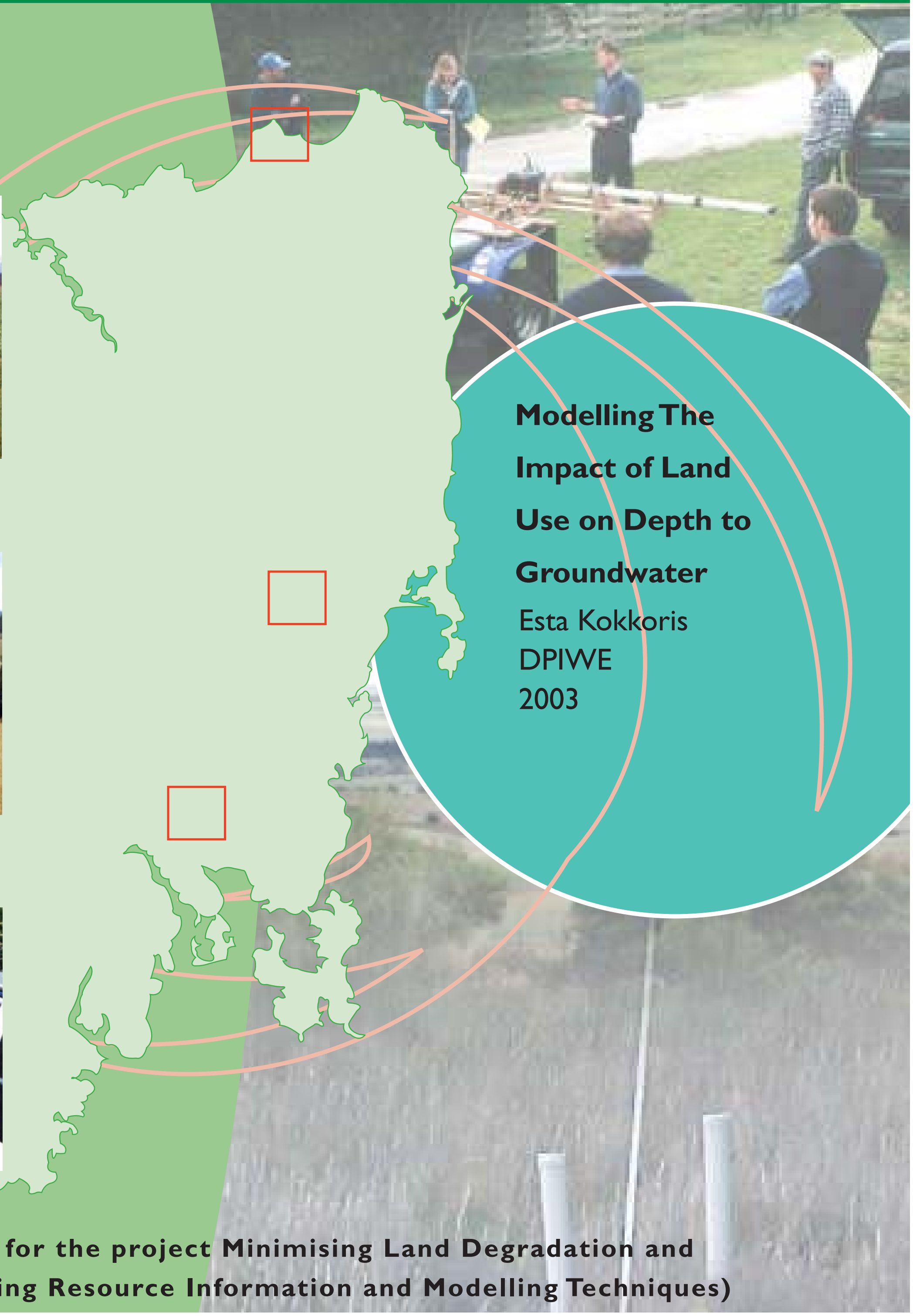
LAND DEGRADATION SALINITY RISK PROJECT

Water Balance Modelling



# Modelling The Impact of Land Use on Depth to Groundwater

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DPIWE
2003

(A sub report for the project **Minimising Land Degradation and Salinity Risk Using Resource Information and Modelling Techniques**)

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# CONTENTS

# LIST OF FIGURES

# LIST OF TABLES

# SUMMARY

Tasmania is currently experiencing an expansion of irrigated farming systems into low rainfall (<750 mm) areas particularly in the south of the state. A lack of appropriate land resource information in areas of greatest land use change, principally where pastoral grazing enterprises are making way for irrigated agriculture, means that the potential impact of changes in land management upon natural resources remains difficult to assess.

The Minimising Land Degradation and Salinity Risk project was established to address the issue of the potential impact of land use change on resource condition. It is well known that salinity is an issue in many of these areas experiencing land use change and that there exists a real need for tools that can predict the impacts of changing land use on conditions such as depth to groundwater and groundwater quality. A modelling approach was considered as one means of approaching this problem and thus this component of the overall project was developed to identify and test various modelling approaches that would be suitable for salinity risk assessment in the Tasmanian context.

The status of salinity research from across Australia was extensively reviewed to identify an appropriate salt budget model for use in Tasmania to compare and contrast salt accumulation in soils under different land uses practices. Some of the reviewed models such as SaLF, SODICS and Hydrus2D, have the capacity to estimate salt accumulation but lack the ability to adequately model and compare changing land use management practices. Some models such as PERFECT, SaLF, SODICS and SWIMv2 were developed for areas with vastly different climate, soil and crop systems to Tasmania. The SWIMv2 and Hydrus2D models require extensively detailed experimental data, which is not available in Tasmania and conversely the AgET model, is too simplistic to give the answers required for the case study. Other models such as APSIM and SWAGMAN have the capacity to compare deep drainage under different cropping systems but require crop and soil data that are not available for Tasmanian areas and crop types.

A pre-experimentation water-balance investigation in a case study area was completed with simulation of the effect of different land management scenarios upon deep drainage using a computer water balance model. The water balance model WAVES was used to model land management scenarios to better reveal the complexity, episodicity and relative magnitude of the effect of changes in farming systems have on the amount of long-term deep drainage.

Key results of the case study suggest that with current irrigation methods and irrigation scheduling techniques, the contribution of irrigation to deep drainage is not likely to be as great as the changes induced by changing land management from perennial pastures to annual cropping rotations. The study also strongly suggests that further work is required to continue modelling the water balance with one of the next generation of water balance models available. A major drawback of continued modelling work is most models that could be used have been developed in mainland regions of Australia using information about mainland crops and soils. Further modelling, therefore, will require the gathering of natural resource data sets to facilitate calibration of these models to Tasmanian conditions and the validation of modelling results.

It is recommended that the modelling approach is continued in Tasmania and that the APSIM and/or SWAGMAN models are developed for salinity risk modelling. This will require experimental work to obtain information about the hydrology and chemistry of soils, phenological descriptions of commonly grown crops, and detailed climate information (amount of rainfall, intensity of rainfall, sunlight hours, and humidity conditions). Quantitative yield and irrigation quantity information would also be advantageous. Development of the models will also require a multi-disciplinary project team to facilitate the gathering of data and to complete scenario modelling with model calibration and validation of results. Ultimately it is the farmers who will be the end users of model outputs and it is envisaged that a user friendly version of the model will be available to non-technical end users to help in land use change decisions. Both APSIM and SWAGMAN have tools and capabilities in place to support this.

# 1. INTRODUCTION

Tasmania is currently experiencing an expansion of irrigated farming systems into low rainfall (<750 mm) areas traditionally used for extensive grazing enterprises. In some of these areas there is a known salinity hazard present and a significant risk of secondary salinity arising from salt accumulation and rising groundwater induced by this land use change. Despite our understanding of salinity processes and the extent of the issue, there is little available to assist farmers in assessing their risk from salinity under various land management options. Long term experimental and natural resource data on the effects of land use change on salinity risk are also unavailable for the Tasmanian system. Modelling techniques can be used as tools in areas lacking large data sets to assess the relative risks of secondary salinity occurring as a direct result of land use change and the introduction of irrigation.

The aim of this study was to identify suitable modelling tools that will assist farmers with a better understanding of the potential impacts of land use change on the soil water balance in order that they may make better informed land management decisions to minimise the risk of secondary salinity. Specifically the three key objectives of the project were:

- Review the status of current salinity modelling approaches across Australia and overseas and identify a suitable salinity modelling approach for use in Tasmania.

- Based on the findings of the review and using available resource information from current study sites, use a modelling approach to determine salinity risk depending on soil physical and chemical properties and ground water status using the Coal River Valley as a study area.

- Use the model to compare the effect on deep drainage (in a range of soil types) of climate, annual versus perennial crops, and irrigation, and to carry out the comparisons based on long-term meteorological records (25-50 years).

# 2. MODELLING THE WATER BALANCE AND DEEP DRAINAGE

Secondary salinisation is largely related to an imbalance in soil hydrological processes resulting from the direct influence of human activity. Land clearing together with a change to European farming styles, and the introduction of irrigation are responsible for the shift in the water balance of catchments towards increased accession of water to the groundwater system (Greiner 1997). Perennial native vegetation is able to use a large proportion of rainfall via direct interception by leaves and exploitation of soil moisture by deep expansive root systems. Shallow rooted crops used in modern farming systems use less of the water added to the system, via rainfall and irrigation, allowing more of the infiltrated water to drain out of the root zone and reach the groundwater system. Additionally, during fallow periods there are no plants to use incident rainfall and drainage rates increase further. Figure 1 shows the amount of infiltrated water (from incident rainfall) 'leaked' by native perennial plant systems, agricultural perennial plant system, and agricultural annual plant systems.

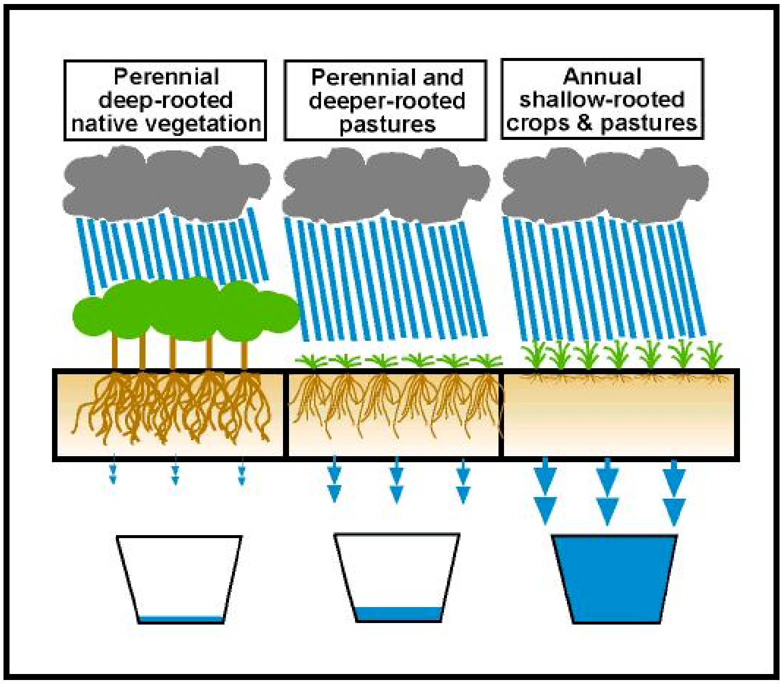

**Figure 1.** Schematic of the amount of infiltrated water (from incident rainfall) 'leaked' by various plant systems.

Infiltrated water that escapes the surface soil layers to a depth beyond plant roots is called deep drainage or potential recharge and is assumed to eventually reach and recharge the groundwater system if no impeding layers exist to prevent its movement. Water that drains beyond the root zone may flush stored salt out of the soil profile and into the groundwater system. If the groundwater system is confined in the landscape it can rise and approach the soil surface resulting in waterlogging and salinisation. In irrigated areas the same process occurs but may be enhanced if more water is applied than can be used by the crop. Determining the water balance for a system is complex and involved, requiring considerable amounts of information on climate, soils and plant physiology. Simplified water balance models are the preferred tool for the comparison of various land management techniques on the accumulation, movement, and quality of water moving through the soil profile. Water balance modelling investigates the contribution to deep drainage of excess water in the soil system from rainfall or water application from irrigation, and from this the risk of salinisation occurring can be inferred.

The effect that climate, vegetation and soil have on the water balance may all be further influenced and changed to some degree by land management change. How such changes impact on the water balance and most importantly on deep drainage over time is difficult to interpret. The capacity to measure with some confidence the relative magnitude of deep drainage beneath agricultural systems does exist using careful physical measurements and analyses (Zhang et al 2002) but there are, however, few actual water balance studies of deep drainage in Australia.

Direct measurement of the components of the water balance can be time consuming, require specialist expertise and replication of fieldwork is expensive. Field techniques alone cannot answer questions about how long term land use changes affect the water balance (Zhang et al 2002). More often than not modelling is used as a stand-alone tool or in conjunction with field measurements to provide long term deep drainage estimates thus avoiding some of the time and monetary constraints associated with direct measurement. Furthermore, the comparison of the variation of deep drainage under different land management systems over time remains a difficult task due to the time and expense needed for fieldwork and replication of measurements. Long term estimates of deep drainage rates are required to understand the way current farming systems affect the soil water balance. Understanding the interactions between land management, climate and water balance is critical in assessing the salinisation risk of new and existing management options and for developing sustainable cropping systems. The use of water balance models to simulate long term deep drainage rates under a range of climatic conditions, management options and other site variables is common in Australia, especially where natural resource information may be scarce.

Modelling is able to separate factors that may confound experimental studies, such as variable weather and soil types and variable land management (Connolly et al 2002). Simulation studies are quick and easy to run for long climate sequences (>30 years) and for a larger range of treatments than experimental studies. The power of the one-dimensional water balance models is not to predict absolute quantities of deep drainage for specific sites or situations but to analyse likely trends, changes or impacts on the water balance that result from land use change.

Water balance modelling looks at the effect of climate, soils, vegetation and land management upon the different components that make up the soil water balance. The water balance states that any change in water content of a given soil volume during a specified period must equal the difference between the amount of water added to the volume of soil and the amount withdrawn from it (Zhang et al 2002). Hence the water content of a soil will increase when additional water is added via infiltration or capillary rise and decrease when evapotranspiration or deep drainage withdraws water. The water balance can be calculated for any soil volume but for the purpose of deep drainage estimation the root-zone is generally the depth considered (Zhang et al 2002). A simple diagrammatic water balance model is shown in Figure 2. Inputs of water to the root zone come from precipitation and irrigation and watertables that lie within two metres of the soil surface with water moving towards the surface by capillary rise. Changes to the water balance, such as an increase in deep drainage due to land clearing or land use change are believed to be the principle driver of increased secondary salinisation.

One of the most important inputs for a water balance model is climate data. Rainfall amount and distribution over time are the minimum requirement for any modelling study. In temperate to tropical parts of the country normal rainfall can exceed the potential evaporation for part of the year leading to deep drainage when excess water saturates the soil. In arid areas deep drainage occurs mainly as a result of intense rainfall and flooding that occur episodically. When estimating the contribution of through flow to the magnitude of deep drainage the temporal distribution of rainfall is as important as the total amount of rain. The sequence of rainfall events together with the seasonality of rainfall determines the episodic nature of deep drainage (Walker et al 1999). Tasmania has winter dominant rainfall patterns with most rain falling within the cooler part of the year when evaporation and the amount of water the vegetation uses is low. It is during such times that the potential for deep drainage is likely to be high. If the soil is already nearing its saturation point deep drainage is more likely to occur.

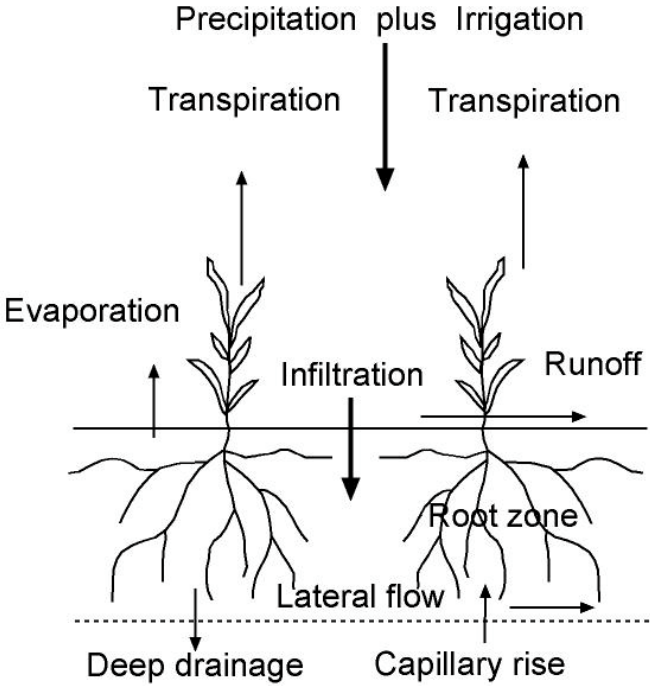

**Figure 2.** Schematic of the water balance for a root-zone (after Walker and Zhang 2002).

The role of vegetation as it impacts on deep drainage depends on the nature of vegetation growth. The depth of plant roots and whether they are perennial or annual affects the amount of deep drainage that can occur. The effect of perennial native vegetation, perennial agricultural plants and annual agricultural plants on deep drainage is shown in Figure 1. Deeper roots allow plants to extract water from deeper in the soil thus reducing the amount of water that can leak below them. The rooting depth of some native perennial species can reach up to 40 metres. Many agricultural species have roots that grow to less than 1-2 metres deep and consequently have a lower capacity to extract water before it flows past them (Walker et al 1999).

Furthermore perennial vegetation grows all year round and subsequently uses water, either from precipitation or wet soil, in most seasons. During the drier seasons perennial plants adapt by sending down deeper roots to find extra water. Perennials are also adapted to shut down during intense dry periods and to respond to occasional rainfalls during these periods. Perennial plants are not always able to utilise water as rapidly as it is supplied, however. Perennial pastures in some winter dominant high rainfall regions (>750 mm annually) can have difficulty in reducing excess deep drainage that occurs in the winter (Walker et al 1999).

Annual plants grow, flower, set seed and then die. They use water only while they grow (during late winter and spring) and are generally shallow rooted because they do not need deeper roots for the drier parts of the year. In annual crop rotations the ground may be left bare of vegetation for part of the year while the new plants germinate and establish. This fallow period most often falls during the cooler wetter months in Tasmania leaving the soil without vegetation cover to use up the rainfall, thereby increasing the possibility of increased deep drainage and subsequent groundwater recharge.

The textural properties of soil impact on deep drainage by affecting the water holding capacity. The water holding capacity of a soil is the amount of water a soil can hold in between field capacity and wilting point conditions. Sandy and rocky soils have low capacity and it is expected that deep drainage is greatest on these soil types compared with heavier clay or loam soils all things being equal (Walker et al 1999). Clay soils can store a great deal of water and have low relative levels of deep drainage but little of the soil's stored water is available to plants. Deep drainage on cracking clay soils may also be very high initially when water is first applied to a dry cracked soil because water flows preferentially down the large cracks produced when this type of clay dries out. Once the soil becomes wet and the cracks disappear the cracking soils behave much like any other heavy clay soil.

Soil permeability also affects how water will move through the soil. The most common example of this is where subsurface clay may be less permeable that the top soil and reduces the rate at which water can move through it and out of the root system. In such circumstances water may move laterally along the sub soil boundary if there is adequate slope or it may build up and form a 'perched' water table system that may lead to localised waterlogging and salinisation (Walker et al 1999). The growth of plants may be impeded by the physical (soil density or hard soil layers) or chemical (acidity, salinity, nutrients) nature of the soil. This restricts the growth of the roots and their ability to use water before it leaves the root zone.

# 3. REVIEW OF MODELS

Disruption of the water balance brought about by land use change is a known factor in the development of salinity. In regions where salinity hazards exist a change in the water balance may exacerbate the development of salinity. Water balance modelling, therefore, provides the ability to analyse the impact land use and management have on the water balance, groundwater interactions and salinisation in a number of ways:

- Objectively analyse climatic data to determine in which areas certain land use options will be effective in managing the water balance since the temporal distribution of rainfall is one of the key drivers of the episodicity of deep drainage.

- Analyse which factors are important in determining excessive deep drainage so that results can be transferred from one field to another with limited additional field work. If land management is the key factor affecting deep drainage rates then the findings from a modelling study may be applicable to other areas with similar soil type and climate.

- Extrapolate results from short-term field trials over periods of years to incorporate climate variability into the analysis.

- Provide a basis for the economic analysis of alternative land use systems by predicting both changes in the water balance and in production.

- Help set priorities for field experimentation and data collection.

- Help define in areas of known hazard what land management will best control excessive deep drainage and potential salinity risk.

Modelling also performs a social and educational role allowing landowners and catchment groups to think through a number of 'what if' situations, become comfortable with them, help set priorities and to define the questions that they should be asking (Walker and Zhang 2002).

A number of water balance models exist which have different input requirements and achieve slightly different things. However, all water balance models aim to estimate the components of the water balance, primarily deep drainage and runoff. Additionally more advanced models also aim to estimate crop yields.

## 3.1 Models Reviewed

The following models were reviewed for their potential to be used in a Tasmania case study area for the investigation of the effect of land use changes upon deep drainage and salinity risk.

### 3.1.1 AgET

AgET is Agriculture Western Australia's standard water balance calculator developed as an extension tool to assist in the exploration of the water balance components associated with different planting and cropping options. It helps farmers and their advisers to understand how differing climates, plants, soils and rotations influence components of the water balance.

AgET uses average climate and representative soil and plant information from agricultural areas of Western Australia and is a simple model with three or so parameters. The model offers quick advice on the potential effectiveness of land use options in controlling salinity. It is a point scale model that provides a surface water balance under conditions of climate, soil, and land at any point.

AgET was only designed to demonstrate processes and likely outcomes. It is not designed to solve the water balance for complex situations. Nor is it suited to areas where root-zone and water tables are in contact ie discharge areas. The model does not measure plant water use but it estimates total evapotranspiration from a series of crop factor parameters. Water characteristics of the soil are specified by the lower limit (wilting point), drained upper limit (field capacity) and saturated volumetric water contents. AgET was partially converted to use Tasmanian data by incorporating estimates of the water holding characteristics (field capacity, wilting point etc) of Tasmanian soils as presented by Cotching et al (2001, 2002a, b, c). The original Western Australian vegetation crop factors were retained with some information from New South Wales also sourced from the Wise Watering Irrigation Management Course Manual (2001). Investigation of crop factors relevant to Tasmanian crops is needed if AgET is to be used by farmers. A GIS with Tasmanian locations linked to Tasmanian climate information for certain regions was also incorporated The AgET model allows farmers to ask ‘What if’ questions about alternative farming systems.

### 3.1.2 SaLF (Salt and Leaching Fraction)

The Queensland Department of Natural Resources produces SaLF. The model predicts the effects of irrigation on soil root zone salinity and leaching fraction using key soil properties (cation exchange capacity, clay percentage, and exchangeable sodium ration) and water inputs (rainfall and the electrical conductivity of irrigation water).

NP. SaLF is a steady state salt balance model and can be used to determine the sensitivity of soils to changes in land management.

SaLF is based on a model incorporating soil particle packing theory, rainfall amount, the role of exchangeable sodium and electrolyte concentration on soil permeability and the influence of clay content and mineralogy on soil behaviour. It does not incorporate any measurement or estimation of water uptake by plant roots. For the purpose of the case study SaLF was not appropriate, as it contains no capability to compare the effect on deep drainage of different land management strategies.

### 3.1.3 SODICS (Solute Dynamics in Irrigated Clay Soils)

Initially developed by Rose *et al* (1979) and used in a number of Australian studies, SODICS compares mass storage of solutes in paired soil profiles one of which is under native vegetation and other which has been cleared for a known period. The model uses a mass balance principle that the change in mass storage over the period since clearing is related to the difference in the mass of solute applied to, and leaving the soil profile.

It is assumed that the chloride concentration of the soil water at given depth is a constant proportion of the mean chloride concentration in the zone under consideration. Using two chloride profiles to derive mean chloride concentrations separated in time it is possible to solve for the change in deep drainage rates between the paired soil profiles. As with the SaLF model, SODICS does not have a capability to compare the effect of differing land uses.

### 3.1.4 PERFECT (Productivity, Erosion, Runoff Functions to Evaluate Conservation Techniques)

PERFECT (Littleboy 1989) is a farm systems model designed for the subtropical regions of Queensland. It comprises a series of Queensland Department of Primary Industries crop models and United States Department of Agriculture (USDA) water balance and soil loss models modified for Queensland conditions. Three major model components represent hydrological, agronomic and soil erosion processes. The model calculates crop phenology, leaf area development, dry matter production, root growth and yield for wheat, sunflower and sorghum. In addition the model simulates the soil water dynamics of the modelled system and estimates the annual water balance and soil loss.

The model has been applied to investigations of the effect of soil erosion on productivity, the effect of fallow management on runoff, erosion and yield, the viability of different cropping systems and the impact of proposed climate change for agricultural systems (Littleboy 1994).

The major disadvantage in using PERFECT in the Tasmanian context is that it was developed primarily for subtropical areas and has crop information for a limited number of crops, two of which are not grown in the state. Whilst the model is adaptable to other areas it was outside the capabilities of this case study to take the time and experimental effort required to calibrate the model for conditions in Tasmania.

### 3.1.5 WAVES (Water, Vegetation and Soil)

WAVES (Dawes and Short 1993; Zhang and Dawes 1998) is a model that predicts the dynamic interactions within the soil-vegetation-atmosphere system on a daily timestep. The model consists of four modules that simulate the energy, water, carbon (plant growth), and solute balances. The model uses net radiation from incoming solar radiation, air temperature, and vapour pressure deficit as inputs.

The soil-water balance module handles rainfall and irrigation infiltration and calculates runoff, soil evaporation and plant water extraction, moisture redistribution, and drainage. Soil water movement in both the unsaturated and saturated zones is simulated using a solution of Richards' equation for unsaturated flow. Water tables may develop anywhere within the soil profile as a result of infiltration, or imposed groundwater boundary condition.

To solve Richards' equation, the analytical soil model of Broadbridge and White (1988) is used to describe the relationships between water potential, volumetric water content and hydraulic conductivity ($K_s$), volumetric soil moisture content at saturation ($\theta_s$), airdry volumetric water content ($\theta_d$), soil capillary length scale ($\lambda_c$), and soil structure parameter ($C$). The Broadbridge and White soil model can realistically represent a range of soil moisture characteristics (Broadbridge and White 1988; White and Broadbridge 1988). The Richard's equation only applies to rigid soils (ie those that do not shrink and swell).

Solute transport within the soil column is solved using the convection-dispersion equation (Dawes and Short 1993). It is assumed that the solute concentration does not interact with soil hydraulic properties, so that flow of water and contents are constant with respect to the solutes. The feedback of salinity to plants is through the reduction in apparently available water due to osmotic potential induced by dissolved salt (sodium chloride) alone. WAVES does not model salt movement.

A significant strength of WAVES is that it is a generic model not specifically designed for any particular climate region, soil type or vegetation system. Because of this strength WAVES was considered suitable for use in the case study.

### 3.1.6 SWIMv2 (Soil Water Infiltration and Movement version 2)

SWIMv2 is a model designed to address soil water and solute balance issues. It is based on the Richards equation for water flow and the Convection-Dispersion Equation for solute transport (Verburg et al 1996). The Richard's equation only applies to rigid soils (ie those that do not shrink and swell).

SWIMv2 treats soil as a one-dimensional vertical profile, which may be vertically inhomogeneous, but is assumed to be horizontally uniform. It can be used to simulate runoff, infiltration, redistribution, solute transport and redistribution of solutes, plant uptake and transpiration, evaporation, deep drainage and leaching.

SWIMv2 is not a crop growth model and there is no feedback between plant and soil processes. The limitation is overcome when SWIMv2 is used in a cropping systems framework such as APSIM (described below).

SWIMv2 was designed to look at the short-term infiltration behaviour of intensively monitored sites. It requires information from a soil column that has been extensively tested and understood and where one has a sample at approximately each 10 cm depth interval (Dawes pers comm 2001). The type of intensively monitored soil data best suited to SWIMv2 is not yet available in Tasmania and hence SWIM was not considered suitable for use in the case study.

### 3.1.7 APSIM (Agricultural Production Systems Simulator)

The Agricultural Production Systems Research Unit (APSRU - a joint research unit of Queensland Departments of Primary Industries and Natural Resources and CSIRO Tropical Agriculture) produces the APSIM model.

APSIM has been developed in a way that allows the user to configure a model by choosing a set of sub-models from a suite of crop, soil and utility modules. Any logical combination of modules can be simply specified by the user "plugging-in" required modules and "pulling out" any modules no longer required.

The MANAGER module allows flexible management rules to be included so those complex or conditional management scenarios, including rotations and sowing rules based on soil moisture, can be modelled.

The water balance simulates runoff, evaporation, and deep drainage, and provides water to the crop modules for transpiration. The SoilWat2 module simulates runoff, evaporation and deep drainage and provides water to the crop modules of APSIM for transpiration. It is a cascading bucket water balance model. Water characteristics of the soil are specified by the lower limit (wilting point), drained upper limit (field capacity) and saturated volumetric water contents. Runoff from rainfall is calculated using the USDA soil moisture curve number techniques. APSIM also has the capacity to use SWIMv2 as an alternative water balance estimator.

APSIM is an ideal model for use in the Tasmanian context, however at the time of model investigation there were difficulties involved with getting access to the model and access to training. In the last twelve months the difficulties have been overcome and APSIM has been identified as a good model for potential future modelling studies in Tasmania. Detailed soil, climate, and crop physiology data sets for Tasmania are required to calibrate APSIM for use in this state. Furthermore, establishment of research partnerships between state research bodies to build capacity to develop data sets together with collaborative efforts with CSIRO groups using APSIM will enable the to be put to its best use.

### 3.1.8 HYDRUS 2D

Hydrus 2D comes from the Colorado School of Mines and simulates two-dimensional movement of water, heat and multiple solutes in soil. It solves the Richard's equation for saturated-unsaturated water flow and the convection-dispersion equation for heat and solute transport. The flow equation incorporates a sink term to account for water uptake by roots, and flow and transport can occur in the horizontal and vertical plane.

Hydrus 2D is able to model the movement of salt in the soil in two dimensions and would have been an ideal model to use to investigate the risk of salinisation under irrigation but for two points. The model does not model the interaction of plants and soils and, therefore, does not offer the capability to compare different land uses. Secondly, extensive training is required to be able to use the model and the American course currently occurs only on demand in Australia and is cost prohibitive.

### 3.1.9 SWAGMAN (Salt, Water and Groundwater Management)

Produced by CSIRO Land and Water SWAGMAN comprises several models specifically developed to determine the impacts of management and climate on deep drainage and watertables, on salinisation and yield, and the trade-offs between environmental objectives and profitability. The models that make up SWAGMAN include:

- SWAGMAN Destiny which is a point scale salt and water balance model which can be used to estimate change in crop yield resulting from water table and salt interactions. The model uses fairly readily available soil profile data, together with daily weather data to calculate salt and water balances. The simulated crop responds to stresses from water shortage, aeration, salt and nitrogen shortage.

- SWAGMAN Whatif is a simplified version of Destiny used for educational and extension purposes.

- SWAGMAN Farm is a farm-scale optimisation model that predicts the most economic cropping mixes that meet specified drainage and root zone salinity objectives, taking into account farmer preferences.

- SWAGMAN Options is used to investigate the interaction of a number of paddocks in an irrigation area to determine water use and cropping policies.

- SWAGSIM is a spatially distributed groundwater model to investigate the connection between irrigation and regional groundwater.

The SWAGMAN suite of models directly meets the aims and objectives of the project, however, it was identified too late to be used in this project. It is an ideal tool for use in Tasmania to investigate the risk of salinisation under land use change. As is the case with APSIM detailed soil, climate, plant physiology, crop growth, crop yield and local and regional groundwater data sets for Tasmania are required to calibrate SWAGMAN for use in this state. Furthermore, establishment of research partnerships between state research bodies to build capacity to develop data sets together with collaborative efforts with CSIRO Sustainable Irrigation Systems will enable us to carry out collaborative research in a regional context for Tasmania.

The contact details for each of the models reviewed are contained in Appendix 1.

## 3.2 Conclusion

The models considered and used in this study are all one-dimensional water balance models, which consider water moving vertically but not horizontally in the soil profile. They are most often used to determine the impacts on the water balance of climate, soils and vegetation by determining the magnitude of change of deep drainage rather than absolute amounts. Essentially all the models reviewed work in the same manner. Some, like PERFECT, SaLF and SODICS, have been developed in the sub tropical regions of Australia and have not been calibrated for use in temperate regions. Some, like HYDRUS2D and APSIM require extensive training and up skilling before they can be used. All the models reviewed require parameter information that may not be available in Tasmania. In the case of AgET and WAVES literature sources of information are the best options when real data are unavailable. For other models such as SWIMv2, APSIM and SWAGMAN the data requirements are extensive and use of these models without complete soil and crop parameter data sets is not recommended. A weakness inherent in all of these one-dimensional point scale water balance models (except HYDRUS 2D) is that they do not have the capability to model the spatial effects of land use change. Extrapolating the water balance estimation to infer salinity risk on a larger scale can be problematic because of interactions with catchment or regional scale groundwater processes and lack of knowledge of the deeper geology.

The models reviewed here all employ a range of assumptions and the best current understanding of the water balance system. In many cases, however modelling is the only tool available to obtain a first guess estimate of the dynamics of the system in question before extensive field investigations take place. All models are limited by uncertainty representing the physical system, functionality, complexity and the ability to derive parameter values. In light of available soil and crop data the WAVES model was considered most appropriate for use on the case study. However, the best and most promising models were APSIM and SWAGMAN because they have the capability to compare different cropping systems, crop yields, crop nutrition and deep drainage between different cropping systems. To facilitate the use of APSIM and SWAGMAN in Tasmania work is required to obtain the necessary crop, soil and geology data, currently lacking in Tasmania, required to run the models.

# 4. SALINITY RISK MODELLING STUDY

Following a review of available water balance models WAVES was selected to define generalised relationships between land management and deep drainage for the study area. At the time of the first phase of the model review WAVES was the model chosen as being best suited to the case study. It is a generic model that is not specifically designed for any particular climate region, soil type or vegetation system and in light of resource limitations (cost, time, personnel, data gaps) it was best able to provide the answers required. WAVES is a model that allows the comparison of deep drainage under various land management schemes. The availability of the APSIM and SWAGMAN models was not identified until late in the study period.

## 4.1 Case Study - Coal River Valley

The Coal River Valley covers over 600 square kilometres of south eastern Tasmania. It is located on the eastern fringes of Hobart and the catchment contains a diverse range of land uses including, pastures, forests, recreation, irrigated crop land, and rural residential development. The area selected for use in this case study forms just a part of the Coal River Valley. The location of the Valley and the case study area are shown in Figure 3.

The Coal River Valley catchment is a relatively dry area of the state with an annual rainfall averaging around 500-600 mm. Over the last decade a transition from dryland cropping and grazing to higher value irrigated crops has taken place and this trend is expected to continue. The construction of the Craigbourne Dam on the Coal River in 1986 and the initiation of Stage 1 of the South East Irrigation Scheme (SEIS) provided the substantial resources required for the development of intensive agriculture in the Valley. Using water from other sources such as reuse of sewage effluent may potentially increase the capacity of the SEIS.

The occurrence of soil salinity in the Coal River Valley was first detailed in a survey of the alluvial soils in the lower Coal River Valley by Holz (1987). A subsequent study (Finnegan 1995) found that 13.7% of the total area in the SEIS was saline. Economic necessity has already driven an initial burst of land use change from low value grazing enterprises to irrigated cropping. With the expansion of irrigation resources in the Valley economic necessity may again force a change from lower value irrigated cropping such as lucerne and poppies into higher value crops such as fresh vegetables, vegetable seed and tree fruits, with a corresponding greater demand for water (Hardy 1995). The presence of naturally saline soils and shallow watertables in the Valley indicate the potential for an increase in severity of, and the expansion of area affected by salinity following land use change, particularly irrigation, may be high. However, the effect of land use change upon deep drainage rates and salinisation in the Valley are unsubstantiated. The modelling component of this project was, therefore, designed to assess the relative risks of secondary salinity occurring within irrigated agricultural areas as a direct result of land use change and the introduction of irrigation and to assist farmers in identifying the potential risks of wide scale land use change. The use of water balance modelling techniques as a tool for predicting the impact on the water balance of various land use scenarios is tested here. The project was developed following the expansion of cropping activities, particularly irrigated cropping. This intensification is encouraged by the better profitability of irrigated cropping and the developments in water supply and application technology, so that intensive cropping is now a feasible option for many farmers.

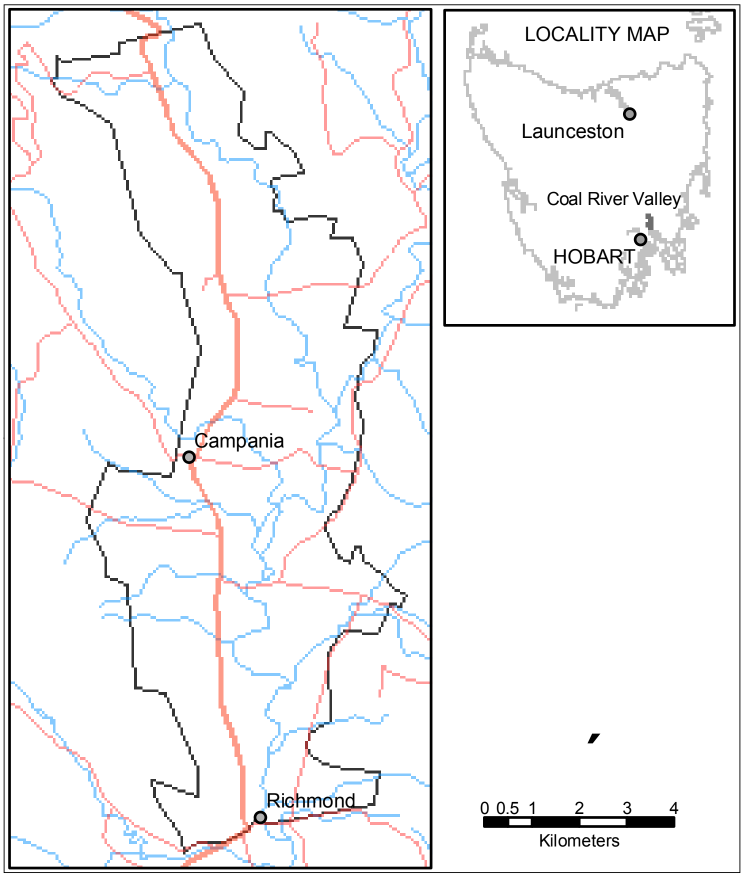

**Figure 3.** The location of the Coal River Valley and the case study area in south eastern Tasmania.

## 4.2 Methods

Our inability to directly measure deep drainage accurately due to the complexity of factors involved meant that the use of modelling instead of physical data gathering was appropriate for the case study. The water balance model, WAVES, that simulates the behaviour of plants, soils and water use over these long time scales, was used to compare the quantity of deep drainage under different land management scenarios typical of the management being used in the Coal River Valley.

For the soil component WAVES requires information about the soil depth, soil layering and the hydraulic characteristics of each layer. Soil information was derived from Holz (199??) for the Coal River Valley. The soils were broadly divided into gradational, sandy duplex, sandy clay loam duplex, uniform clay loam, uniform sand and vertosol.

In the absence of experimental data sets for the Coal River Valley soils the soil hydraulic functions of each layer were assumed to follow Broadbridge and White (1988). The average values of Broadbridge-White soil parameters for generic soil classes are presented in Table 1. The table lists the soil hydraulic parameters associated with the Broadbridge and White (1988) model and required by WAVES. An definition of the parameters can be found in the model review of WAVES in section 3. $K_s$ is the saturated hydraulic conductivity; $\theta_s$ and $\theta_r$ are the saturated and air-dry volumetric water contents respectively; $l_c$ is a capillary length scale related to sorptivity; and $C$ is a shape parameter for the soil moisture characteristic (Salama et al 1999). Values of $K_s$, $\theta_s$ and $\theta_r$ were estimated from the average values in Table 1.1 according to the textures used by Holz (1987) in classifying the Coal River Valley soils. Measured moisture retention curves were not available to fit $l_c$ and $C$ so these values were also estimated from the average ranges for soil textures in Table 1. Table 2 lists the adopted soil parameters used in WAVES for the soils in this study.

**Table 1.** Average values of Broadbridge-White soil parameters for generic soil textures (After Salama et al 1999).

| Texture | $K_s$ (m/d) | $\theta_s$ | $\theta_r$ | $l_c$ (m) | $C$ |
|---|---|---|---|---|---|
| **Sand** | >1.0 | 0.30-0.40 | 0.05-0.10 | 0.02-0.05 | 1.01-1.02 |
| **Loamy sand** | >1.0 | 0.35-0.45 | 0.05-0.10 | 0.02-0.05 | 1.02-1.05 |
| **Sandy loam** | 0.50-5.0 | 0.40-0.50 | 0.05-0.15 | 0.05-0.10 | 1.02-1.05 |
| **Silty loam** | 0.50-2.0 | 0.45-0.50 | 0.10-0.20 | 0.25-0.50 | 1.05-1.20 |
| **Loam** | 0.50-1.0 | 0.40-0.50 | 0.10-0.20 | 0.10-0.20 | 1.40-1.50 |
| **Sandy clay loam** | 0.25-0.75 | 0.35-0.45 | 0.10-0.20 | 0.10-0.20 | 1.40-1.50 |
| **Silty clay loam** | 0.10-0.50 | 0.40-0.50 | 0.15-0.25 | 0.10-0.20 | 1.20-1.30 |
| **Clay loam** | 0.10-0.25 | 0.45-0.55 | 0.20-0.30 | 0.25-0.50 | 1.20-1.40 |
| **Sandy clay** | 0.10-0.25 | 0.40-0.50 | 0.15-0.25 | 0.05-0.10 | 1.10-1.20 |
| **Silty clay** | 0.05-0.20 | 0.45-0.55 | 0.25-0.35 | 0.20-0.50 | 1.05-1.20 |
| **Clay (sandy, light and medium)** | 0.01-0.2 | 0.45-0.55 | 0.25-0.35 | 0.20-0.50 | 1.30-1.50 |
| **Heavy clay** | <0.01 | 0.40-0.60 | 0.05-0.20 | 0.50-2.00 | 1.50-2.00 |

Information on climate was derived from the Bureau of Meteorology from data measured at the Hobart Airport Rainfall station (Station number 094008, Latitude 42.8389 S Longitude 147.4992). The period for WAVES simulations was 1959-2001. This period exhibits a large variation in annual rainfall amount, and therefore large expected variation in annual deep drainage.

WAVES requires 22 parameters to describe the vegetation cover and these are listed in Appendix 2. Most can be measured directly or taken from plant physiological literature. In this project all vegetation parameters were inferred from the literature and existing vegetation descriptions in the WAVES technical report (Zhang and Dawes 1998) for wheat, pasture, and peas. Parameters for orchards were modified from data for gum trees in the manual. Parameters for poppies and brassicas were modified from the wheat and annual pasture files in the manual. No vegetation parameter information was available for any Tasmanian crops and data that was used came from studies in Victoria and New South Wales. There is an obvious absence of vegetation data relevant for Tasmania and the use of mainland data introduced some obvious errors to the model results. The lack of precise vegetation data applies to crop inputs for all models with the potential to be used in this state.

Single vegetation types were modelled for the whole 44 years of the climate file on each soil type to facilitate comparison of the effect of vegetation types upon deep drainage and to document the effect that rainfall distribution has on the episodicity of deep drainage. The vegetation types used were perennial pasture, orchard trees with grassed runs, an annual crop (based on wheat) and fallow soil surface. A series of representative rotations were then modelled over 44 years. From 1959 until 1985 a rotation of eight years pasture followed by wheat, irrigated poppies, wheat, irrigated peas, and irrigated brassicas was modelled. After 1985 the pasture phase was decreased to only five years to represent intensification of annual crop production. The irrigated crops received 5 mm of irrigation water applied approximately every 4-5 days. This level of irrigation was standardised across all irrigated crops from estimations of actual application by a number of farmers in the Valley.

## 4.3 Results

The WAVES model was run to determine deep drainage and runoff characteristics for each major soil grouping in the Coal River Valley under a range of potential land uses, including pasture, irrigated orchards, dryland and irrigated annual crops and fallow.

As can be seen in Figures 4 and 5, for each soil type continuous perennial vegetation (pasture and orchards) allows limited amounts of annual deep drainage. Both pasture vegetation and orchards in this simulation have low rates of deep drainage even under particularly wet years. The years 1961, 1971, and 1986 show peaks of deep drainage on the uniform sand and sand duplex soils, which correspond to peaks in rainfall levels in the same years.

Under continuous annual vegetation (Figure 6) deep drainage follows the same patterns of peaks and troughs as the annual rainfall. When rainfall is high, deep drainage is correspondingly high. The soil type with the lowest overall level of deep drainage is the heavy clay vertosol. The soil types with the greatest overall levels are the uniform sand and gradational soils. Despite the different magnitude of deep drainage between the vertosol and sand duplex both soils exhibit deep drainage patterns that follow the annual rainfall pattern.

Similarly soils left fallow for the simulation period (Figure 7) have deep drainage patterns the same as rainfall and deep drainage rates only moderately higher than the rate under continuous annual cropping.

Figures 8 and 9 present the runoff figures when pasture and annual crops were simulated. As would be expected the soils, which showed high relative rates of deep drainage, have lower rates of runoff. The vertosol soils, as expected, have the highest runoff levels in both instances because they have lower hydraulic parameters than the lighter textured soils which may slow down infiltration and allow more water to flow as runoff.

**Table 2**. Soil type, layering, texture and Broadbridge-White parameters for each soil used in the Coal River Valley.

| Texture | *Depth (m)* | *Texture* | $K_s$ (m/d) | $\theta_s$ | $\theta_r$ | $l_c$ (m) | *C* |
|---|---|---|---|---|---|---|---|
| **Gradational** | 0-0.2 | **Sandy Clay** | 0.100 | 0.400 | 0.150 | 0.150 | 1.500 |
| | 0.20-0.9 | **Medium Clay** | 0.003 | 0.450 | 0.200 | 1.00 | 1.500 |
| | 0.9-2.0 | **Sandy Clay** | 0.100 | 0.400 | 0.150 | 0.150 | 1.500 |
| **Sandy Duplex** | 0-0.4 | **Loamy Sand** | 1.000 | 0.350 | 0.150 | 0.100 | 1.050 |
| | 0.4-1.0 | **Medium Clay** | 0.003 | 0.450 | 0.200 | 1.000 | 1.500 |
| | 1.0-2.0 | **Sandy Clay** | 0.100 | 0.400 | 0.150 | 0.150 | 1.500 |
| **Sandy Clay Loam Duplex** | 0-0.2 | **Sandy Clay Loam** | 0.100 | 0.400 | 0.150 | 0.200 | 1.500 |
| | 0.2-0.9 | **Medium Clay** | 0.003 | 0.450 | 0.200 | 1.000 | 1.500 |
| | 0.9-2.0 | **Sandy Clay** | 0.100 | 0.400 | 0.150 | 0.150 | 1.500 |
| **Uniform Clay Loam** | 0-0.4 | **Sandy Clay Loam** | 0.100 | 0.400 | 0.150 | 0.200 | 1.500 |
| | 0.4-2.0 | **Light Clay** | 0.010 | 0.500 | 0.200 | 0.400 | 1.400 |
| **Uniform Sand** | 0-0.7 | **Loamy Sand** | 1.000 | 0.350 | 0.150 | 0.100 | 1.050 |
| | 0.7-2.0 | **Sand** | 1.000 | 0.400 | 0.100 | 0.030 | 1.015 |
| **Vertosol** | 0-0.1 | **Medium Clay** | 0.003 | 0.450 | 0.200 | 1.000 | 1.500 |
| | 0.1-0.9 | **Heavy Clay** | 0.001 | 0.450 | 0.150 | 2.000 | 2.000 |
| | 0.9-2.0 | **Sandy Clay** | 0.100 | 0.400 | 0.150 | 0.150 | 1.500 |

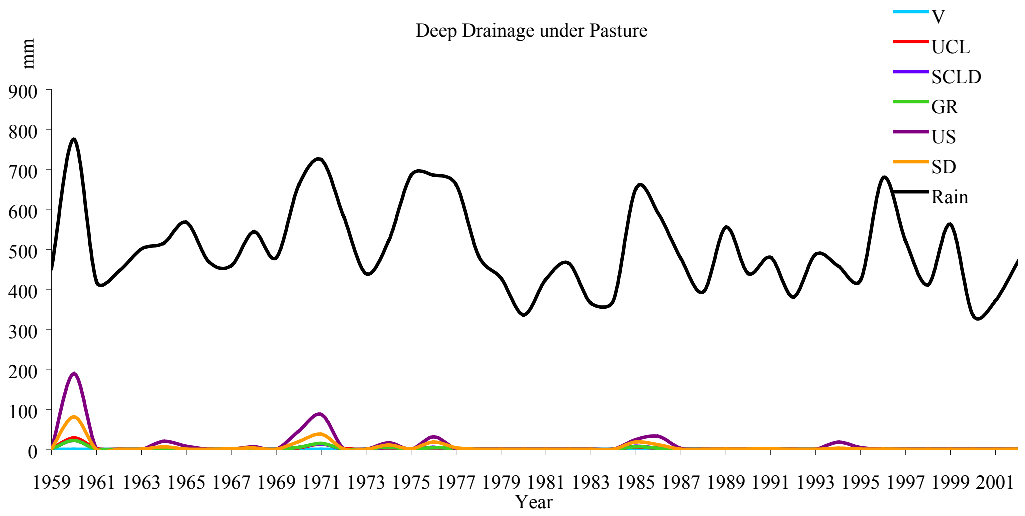

**Figure 4.** 44 years of modelled deep drainage under continuous pasture vegetation where V is Vertosol, UCL is Uniform Clay Loam, SCLD is Sandy Clay Loam Duplex, GR is Gradational, US is Uniform Sand, SD is Sand Duplex soil types.

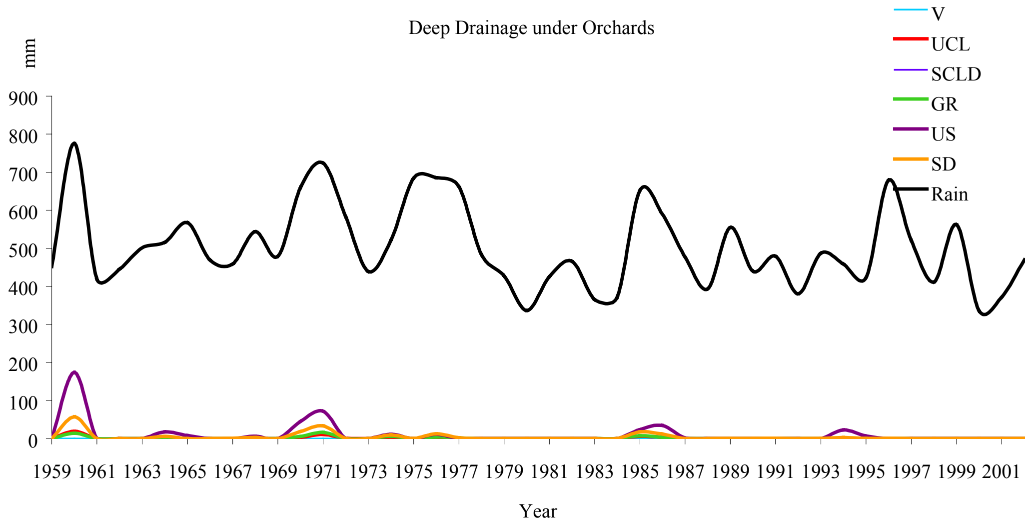

**Figure 5.** 44 years of modelled deep drainage under continuous orchard vegetation where V is Vertosol, UCL is Uniform Clay Loam, SCLD is Sandy Clay Loam Duplex, GR is Gradational, US is Uniform Sand, SD is Sand Duplex soil types.

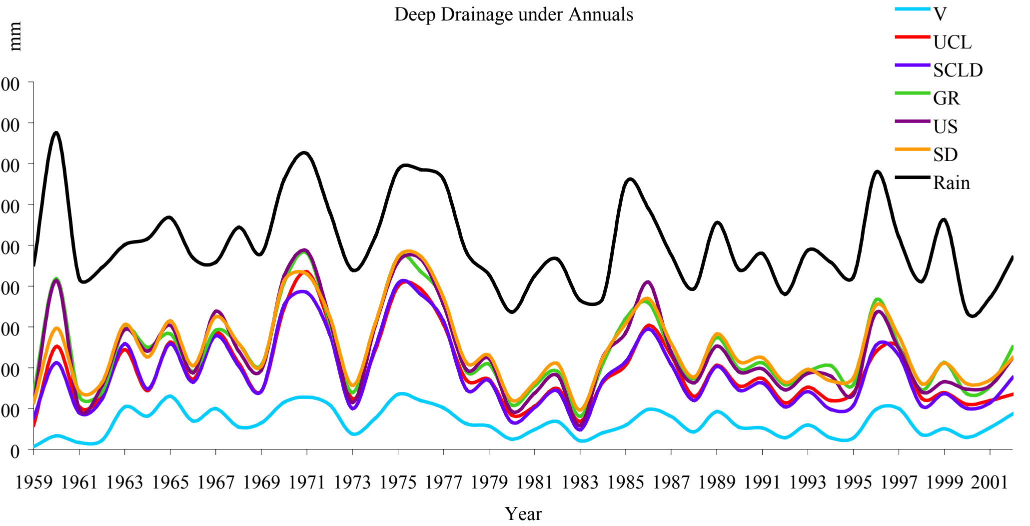

**Figure 6.** 44 years of modelled deep drainage under continuous annual vegetation where V is Vertosol, UCL is Uniform Clay Loam, SCLD is Sandy Clay Loam Duplex, GR is Gradational, US is Uniform Sand, SD is Sand Duplex soil types.

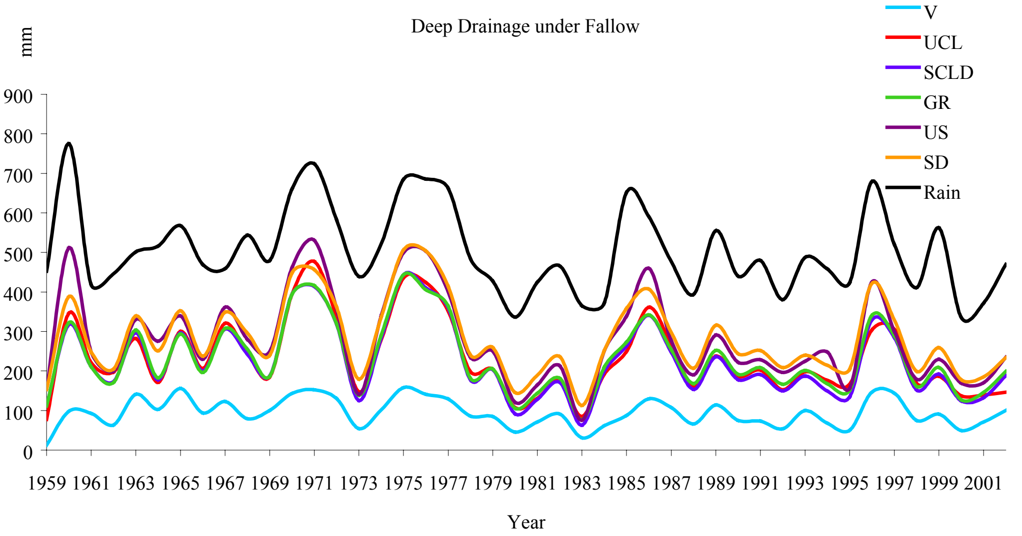

**Figure 7.** 44 years of modelled deep drainage under no vegetation where V is Vertosol, UCL is Uniform Clay Loam, SCLD is Sandy Clay Loam Duplex, GR is Gradational, US is Uniform Sand, SD is Sand Duplex soil types.

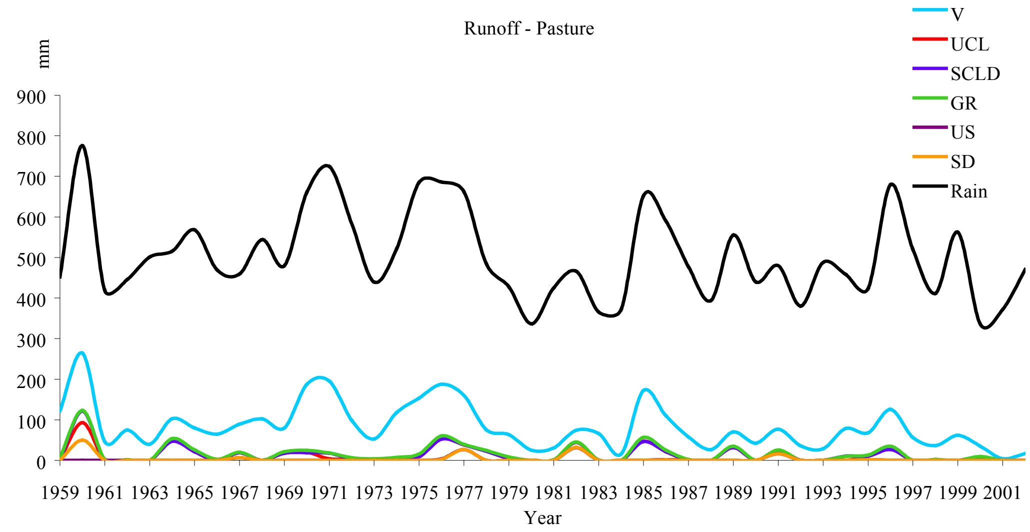

**Figure 8.** 44 years of modelled runoff under continuous pasture where V is Vertosol, UCL is Uniform Clay Loam, SCLD is Sandy Clay Loam Duplex, GR is Gradational, US is Uniform Sand, SD is Sand Duplex soil types.

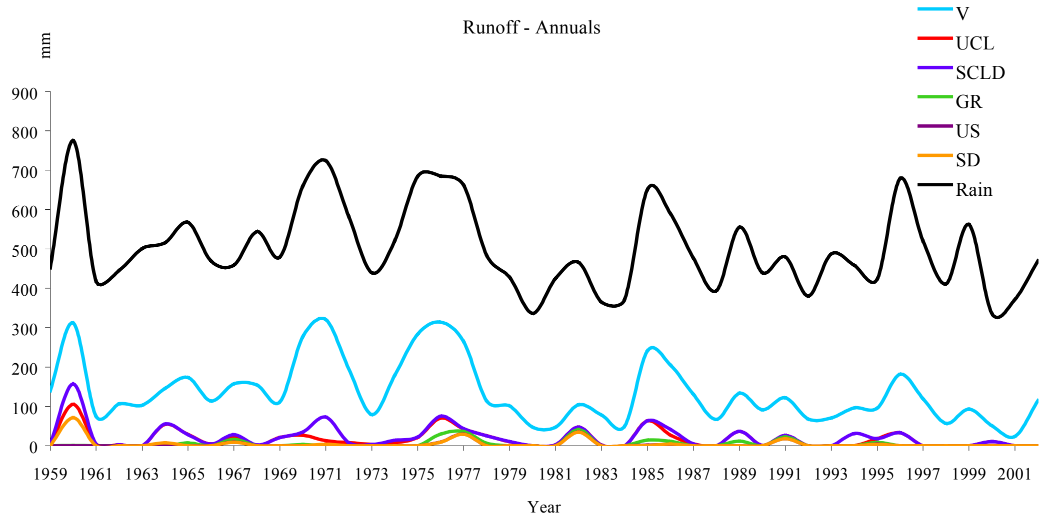

**Figure 9**. 44 years of modelled runoff under continuous annual vegetation where V is Vertosol, UCL is Uniform Clay Loam, SCLD is Sandy Clay Loam Duplex, GR is Gradational, US is Uniform Sand, SD is Sand Duplex soil types.

It is clear from the continuous vegetation simulations that perennial plants are more efficient at reducing deep drainage rates than annual plants. The continuous simulations are not realistic for the Coal River Valley, with the exception of continuous orchard crops, therefore, crop rotations based on actual land use were also simulated. The continuous vegetation simulations did show that episodicity of deep drainage rates is dependent on rainfall distribution even under continuous perennial vegetation cover. Even when low deep drainage cropping management is used deep drainage may still occur at a high level in high rainfall years.

Rotations were modelled for the vertosol and sand duplex soil types because they were the soils that showed extremes of deep drainage levels under the continuous vegetation

**Table 3**. Quantity of deep drainage and runoff under rotation scenarios on a vertosol.

| Year (mm) | Rotation | Rain (mm) | Deep Drainage (mm) | Runoff (mm) |
|---|---|---|---|---|
| **1959** | Pasture | 452.2 | 0.31 | 122.34 |
| **1960** | Pasture | 775.2 | 0.21 | 264.08 |
| **1961** | Pasture | 418.9 | 0.04 | 45.86 |
| **1962** | Pasture | 445.7 | 0.04 | 74.43 |
| **1963** | Pasture | 501.1 | 0.05 | 39.73 |
| **1964** | Pasture | 515.7 | 0.04 | 102.46 |
| **1965** | Pasture | 567.5 | 0.04 | 79.58 |
| **1966** | Pasture | 456.7 | 0.04 | 64.48 |
| **1967** | Wheat | 471.3 | 16.47 | 121.12 |
| **1968** | Irrigated Poppies | 550.7 | 51.55 | 150.74 |
| **1969** | Wheat | 495 | 5.9 | 93.32 |
| **1970** | Irrigated Peas | 673.8 | 86.23 | 273.29 |
| **1971** | Irrigated Brassicas | 755.3 | 145.02 | 338.05 |
| **1972** | Pasture | 594.1 | 3.91 | 96.07 |
| **1973** | Pasture | 387.3 | 0.04 | 27.45 |
| **1974** | Pasture | 573.3 | 0.06 | 141.92 |
| **1975** | Pasture | 684.8 | 0.04 | 152.2 |
| **1976** | Pasture | 682.8 | 0.04 | 186.6 |
| **1977** | Pasture | 663.8 | 0.04 | 158.74 |
| **1978** | Pasture | 470.5 | 0.04 | 75.06 |
| **1979** | Pasture | 440.4 | 0.04 | 63.06 |
| **1980** | Wheat | 336.2 | 3.58 | 38.24 |
| **1981** | Irrigated Poppies | 443 | 41.46 | 31.25 |
| **1982** | Wheat | 481.1 | 10.17 | 95.76 |
| **1983** | Irrigated Peas | 349.2 | 13 | 55.5 |
| **1984** | Irrigated Brassicas | 428.7 | 33.82 | 64.3 |
| **1985** | Pasture | 671.3 | 0.93 | 163.65 |
| **1986** | Pasture | 579.8 | 0.04 | 108.75 |
| **1987** | Pasture | 486.8 | 0.04 | 57.04 |
| **1988** | Pasture | 385.4 | 0.04 | 26.2 |
| **1989** | Pasture | 563.4 | 0.04 | 69.34 |
| **1990** | Wheat | 433.6 | 9.04 | 66.77 |
| **1991** | Irrigated Poppies | 510.8 | 50.33 | 123.66 |
| **1992** | Wheat | 390.5 | 6.55 | 53.77 |
| **1993** | Irrigated Peas | 494.1 | 53.69 | 66.49 |
| **1994** | Irrigated Brassicas | 504.4 | 44.5 | 108.06 |
| **1995** | Pasture | 425.2 | 1.48 | 66.12 |
| **1996** | Pasture | 678.2 | 0.04 | 123.97 |
| **1997** | Pasture | 520.1 | 0.04 | 55.87 |
| **1998** | Pasture | 415.2 | 0.04 | 35.9 |
| **1999** | Pasture | 543.4 | 0.04 | 60.96 |
| **2000** | Wheat | 350.6 | 0.67 | 40.02 |
| **2001** | Irrigated Poppies | 384.5 | 25.28 | 18.7 |
| **2002** | Wheat | 511.3 | 4.71 | 28.17 |

**Table 4.** Quantity of deep drainage and runoff under rotation scenarios on a sand duplex.

| Year (mm) | Rotation | Rain (mm) | Deep Drainage (mm) | Runoff (mm) |
|---|---|---|---|---|
| **1959** | Pasture | 452.2 | 1.38 | 0 |
| **1960** | Pasture | 775.2 | 76.42 | 39.74 |
| **1961** | Pasture | 418.9 | 0.23 | 0 |
| **1962** | Pasture | 445.7 | 0.04 | 0 |
| **1963** | Pasture | 501.1 | 0.74 | 0 |
| **1964** | Pasture | 515.7 | 5.73 | 0 |
| **1965** | Pasture | 567.5 | 0.39 | 0 |
| **1966** | Pasture | 456.7 | 0.11 | 0 |
| **1967** | Wheat | 471.3 | 185.3 | 9.15 |
| **1968** | Irrigated Poppies | 550.7 | 280.43 | 0 |
| **1969** | Wheat | 495 | 114.92 | 0 |
| **1970** | Irrigated Peas | 673.8 | 443.25 | 0 |
| **1971** | Irrigated Brassicas | 755.3 | 477.63 | 3.34 |
| **1972** | Pasture | 594.1 | 18.69 | 0 |
| **1973** | Pasture | 387.3 | 0.04 | 0 |
| **1974** | Pasture | 573.3 | 10.15 | 0 |
| **1975** | Pasture | 684.8 | 0.92 | 0 |
| **1976** | Pasture | 682.8 | 16.71 | 2.53 |
| **1977** | Pasture | 663.8 | 2.8 | 26.42 |
| **1978** | Pasture | 470.5 | 0.15 | 0 |
| **1979** | Pasture | 440.4 | 0.21 | 0 |
| **1980** | Wheat | 336.2 | 47.86 | 0 |
| **1981** | Irrigated Poppies | 443 | 182.93 | 0 |
| **1982** | Wheat | 481.1 | 111.93 | 34.14 |
| **1983** | Irrigated Peas | 349.2 | 103.43 | 0 |
| **1984** | Irrigated Brassicas | 428.7 | 223.14 | 0 |
| **1985** | Pasture | 671.3 | 21.99 | 0 |
| **1986** | Pasture | 579.8 | 8.45 | 1.16 |
| **1987** | Pasture | 486.8 | 0.05 | 0 |
| **1988** | Pasture | 385.4 | 0.12 | 0 |
| **1989** | Pasture | 563.4 | 0.24 | 0 |
| **1990** | Wheat | 433.6 | 112.08 | 0 |
| **1991** | Irrigated Poppies | 510.8 | 247.2 | 17.82 |
| **1992** | Wheat | 390.5 | 90.62 | 0 |
| **1993** | Irrigated Peas | 494.1 | 216.21 | 0 |
| **1994** | Irrigated Brassicas | 504.4 | 216.75 | 0 |
| **1995** | Pasture | 425.2 | 10.92 | 1.82 |
| **1996** | Pasture | 678.2 | 0.55 | 0 |
| **1997** | Pasture | 520.1 | 0.13 | 0 |
| **1998** | Pasture | 415.2 | 0.04 | 0 |
| **1999** | Pasture | 543.4 | 0.15 | 0 |
| **2000** | Wheat | 350.6 | 29.88 | 0 |
| **2001** | Irrigated Poppies | 384.5 | 167.45 | 0 |
| **2002** | Wheat | 511.3 | 79.91 | 0 |

simulations. Tables 3 and 4 list the quantities of deep drainage and runoff calculated by WAVES for the scenario modelling on the vertosol and sand duplex soils respectively.

Figure 10 shows the rotations modelled on a vertosol soil. Generated runoff is again higher than recharge for this soil type and this is also clearly shown in Table 3. It is clear from Table 3 that high levels of runoff generally correspond to large amounts of rainfall and vice versa. Deep drainage occurs under all vegetation types but it is clear that drainage under irrigated cropping phases is high compared to drainage under pasture, which is usually less than 1mm. Deep drainage under wheat is consistently low on the vertosol because of high runoff values and that there was no irrigation for this crop.

The simulation of rotation cropping on sand duplex is shown in Figure 11. Runoff is at a minimum in this scenario and only occurs in some years where rainfall exceeds 425mm as shown in Table 4. Deep drainage occurs under both irrigated and dryland cropping, however, drainage in years of irrigation is higher than in years of dryland cropping and this is clearly shown in Table 4 except in 1982/83 where drainage under wheat is marginally higher at 111.93mm that under irrigated peas with 103.43mm. Deep drainage is high during the first pasture rotation during a period of very high rainfall (775.2mm) in 1960, but then settles to low levels of drainage during subsequent pasture phases.

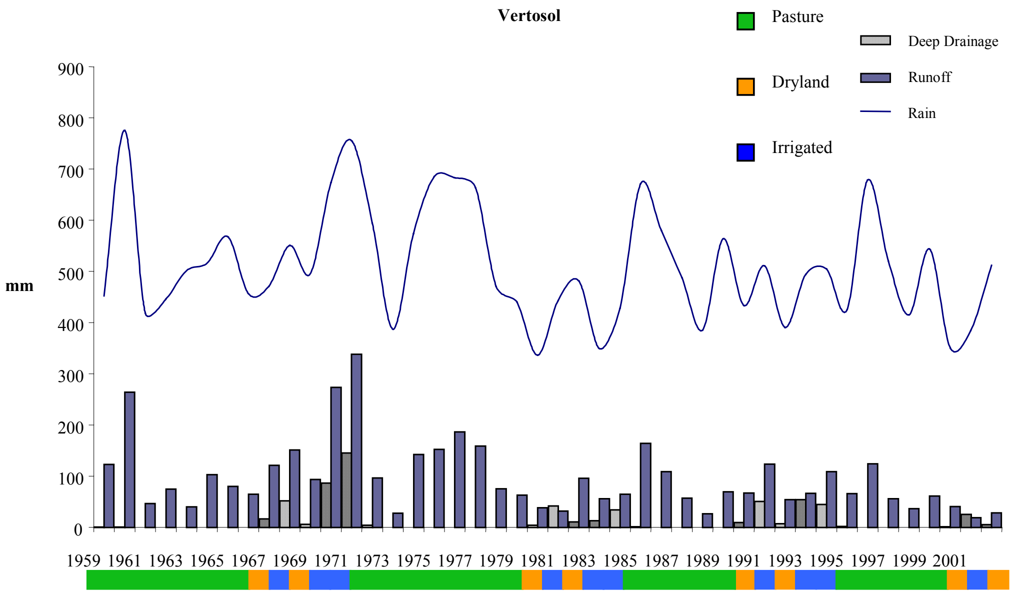

**Figure 10.** 44 years of modelled deep drainage and runoff under crop rotations on a vertosol.

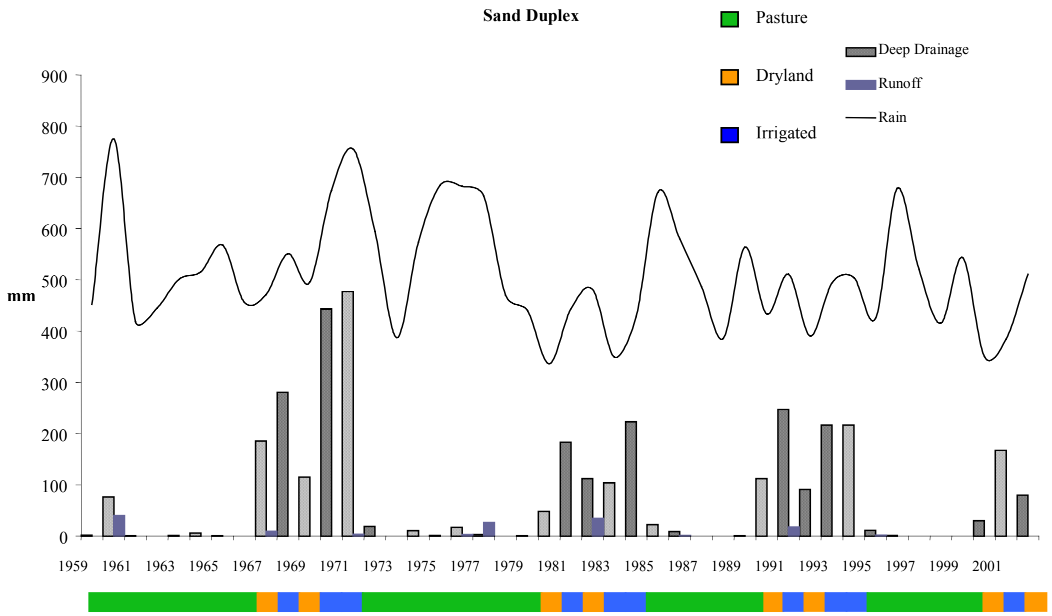

**Figure 11.** 44 years of modelled deep drainage and runoff under crop rotations on a sand duplex.

It is clear from the simulations of crop rotation that perennial plants are again more efficient at reducing deep drainage rates than annual plants. These simulation results indicate that a change from a perennial system to an annual system has a greater impact on deep drainage that a change from dryland to irrigated cropping.

## 4.4 Conclusions

With current irrigation methods and irrigation scheduling techniques, the contribution of irrigation to deep drainage is not likely to be as great as the changes induced by changing land management from perennial pastures to annual cropping rotations. This was demonstrated in Figures 10 and 11 where deep drainage of irrigated and non-irrigated annual crops is similar. The greatest change in deep drainage rates comes from the change from perennial systems to annual systems.

The WAVES model works in one dimension only, vertically, and therefore there is a risk that the modelled results may be over or under estimating the actual amount of deep drainage. Some of the deep drainage rates, which appear high, could be overestimated because the soil and vegetation parameters have been largely estimated for this study. What is important in the simulation results is not the actual amount of deep drainage in each year but rather the change in magnitude of drainage when moving from one land use type to another. Changing from perennial systems to annual systems allows more water to drain out of the soil root zone. The risk of salinisation occurring is high in these cases when drainage increases in areas of known salinity hazard. In the Coal River Valley there are present naturally saline soils and shallow watertables. Excessive deep drainage, such as WAVES indicated is possible under annual cropping, in areas where these hazards are present may adversely affect the occurrence of salinity. Drainage water recharging shallow groundwaters may cause rising watertable levels and drainage moving through salty soils may mobilise salts into the groundwater system or cause discharge of salts in other parts of the paddock, farm or region.

The reality is, however, that most farmers have to incorporate annual crops into their rotations and therefore some deep drainage is likely to continue. However, there remain opportunities to minimise deep drainage. Using cover crops and shortening fallow periods in between rotations is one method that can be used to reduce the overall annual deep drainage rates. Reducing the number of years of annual cropping may also be an option, as is the incorporation of annual pasture crops between annual crops. The use of lucerne is advocated in mainland areas as a method of using excess soil moisture between annual cropping phases. The benefits of using lucerne in rotation in Tasmanian farming systems is an area that demands further research.

This study deals with a complex environmental problem and the scope of the study is limited. The results presented reveal comparatively the impact of land management on soil water balance and potential recharge.

The results presented here are preliminary because of the following limitations:

- In this study the climate information comes from a weather station that is outside of the study area.

- Deep drainage is a relatively small component of the soil-water balance and the difficulty in estimating it is because small errors in estimating or measuring rainfall and evapotranspiration are likely to be larger than the deep drainage (Walker et al 2002). The climate file used was near complete. However, some measures of rainfall intensity were missing from the file and had to be estimated. Errors in this type of estimation may be magnified in the deep drainage estimates.

- Parameter specification especially for below ground parameters such as hydraulic conductivity and their degree of spatial variability, is an important limitation of applying water balance models to deep drainage estimation. The standard method is to infer spatial patterns from soil survey and assume homogeneity within each soil unit. This is an acknowledged fiction but in the absence of data to the contrary is unavoidable.

- Generalised synthetic soil profiles were used which were based on literature values from Holz (1987). Similar soil types in the Coal River were lumped together into broad groupings such as Uniform Sands or Uniform Clay Loams even when there was variation between the similar soil types in order to keep the number of different soil types to a minimum. Soils were built around those classified by Holz (1987) and from Broadbridge and White parameters.

# 5. OVERALL DISCUSSION AND RECOMMENDATIONS

This modelling study was the first of its kind to be undertaken in Tasmania. The time scale in which the study was completed was not adequate for model calibration or validation of results to be undertaken, however the modelling project did serve to show how changes in land use can affect deep drainage and demonstrated the capacity of the modelling approach for future work. The modelling work allowed us to generate approximations based on the best available data in Tasmania.

Undertaking a modelling study of this scope show cased the usefulness of modelling as a tool in salinity risk assessment and highlighted where there are gaps in natural resource management data sets in Tasmania. Much of the data used in this case study was established from the literature. Vegetation parameters were modified from CSIRO records for mainland crops. Soils were based loosely around an early study in the Coal River Valley and existing soil models used previously by other authors with WAVES. Irrigation amounts and frequencies were generalised from discussions with farmers because no records of the daily application of irrigation water exist. Detailed daily climate information was not available from within the study area and was sourced from well outside the area. Little soil and vegetation information exists for Tasmanian farming systems. To adequately model these systems information about the hydrology and chemistry of soils is required, along with phenological descriptions of commonly grown crops. Such information requires repeatable experimental field work over two to three growing seasons. Detailed climate information (amount of rainfall, intensity of rainfall, sunlight hours, and humidity conditions) would also be advantageous since meteorological stations measuring these parameters are often located well outside of farming areas.

This study is not wholly representative of Tasmanian farming systems primarily because the vegetation information used for the annual brassica, pea and poppy crops was spliced together from the literature and the author's knowledge of plant physiology. The wheat, pasture and orchard information was sourced from Victorian examples in the WAVES technical manual which, barring climatic and growth phase differences, is thought to be reasonably representative of these crops in light of the absence of Tasmanian data sets. The orchard simulation can be applied to the growth of vineyards and any other perennial woody crops. Measured physiological data for orchards and vineyards are, however, the ideal.

The review of other models uncovered two models, APSIM and SWAGMAN, with the potential to be used for further modelling studies in this state. APSIM and SWAGMAN have a greater capability to deal with all aspects of cropping systems from land use management to plant nutrition and can estimate deep drainage and also crop yields and economic returns as well as being able to answer the 'what if' questions posed about earnings and sustainability when farmers consider changing their land management. Modelling investigations benefit most from a multi-disciplinary team approach to the work, a team that consists of model programmers and experts, hydrologists, agronomists, soil scientists and economists. The basis for such a team is available already in Tasmania. Models such as APSIM and SWAGMAN also come with the technical backing and support of the organisations that developed them.

The recommendations that come out of this study are:

- To continue with the modelling approach to salinity assessment by developing either APSIM or SWAGMAN for Tasmanian conditions in a multi-disciplinary cross-divisional capacity. Either model is suitable and much depends on the progress of CSIRO's move to implement APSIM into Tasmania in the near future using members of their own staff to facilitate such a move. Contact has been made with key scientists supporting the use of both models and support is available for their use. Both models also support the use of model versions by non-technical end users to answer 'what if' questions about land management change.

- To use the expertise available in the state to measure and develop natural resource data sets that will enable the calibration of these models for Tasmania and allow model results to be validated. The data sets of utmost importance for modelling studies are; data about the phenology, leaf area characteristics and yields of major Tasmanian crops; long term groundwater level data to benchmark the results we have to date; detailed information about the geology underlying agricultural regions; extensive soil hydraulic information for all major soil types; better documentation of irrigation practices; and detailed climate information for major agricultural regions.

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# APPENDIX 1. LIST OF WATER BALANCE MODELS REVIEWED.

| | Aim of Model | Target Use | Advantages | Disadvantages | First point of contact. |
|---|---|---|---|---|---|
| **AgET** | To estimate the water balance model using default crop and soil data easily accessible to non-expert users. | Primarily designed as an education and extension tool from inception. | Default soil and crop data come with the model for ease of use by non-expert users. Second level of data editing available for more accomplished users. Very simple to use and understand. | Lacks adequate detail to be any more than a basic 'what if' calculator. | Rob Argent, The University of Melbourne<br>Phone (03) 8344 7115<br>r.argent@unimelb.edu.au |
| **SaLF** | To predict the effects of irrigation on soil root zone salinity and leaching fraction. Also determines sensitivity of soils to changes in land management. | Researchers, university lecturers and consultants. | Steady state salt balance model - predicts deep drainage and salinity of the root zone and likely effect on plants. | Does not allow adequate comparison of different vegetation management scenarios. | Ian Gordon, Department of Natural Resources, Indooroopilly Sciences Centre, 80 Meiers Road Indooroopilly 4068 Phone (07) 3896 9471<br>Ian.Gordon@dnr.qld.gov.au |
| **SODICS** | To compare mass storage of solutes in paired soil profiles one of which is under native vegetation and the other which has been cleared for a known period. | Researchers | Allows comparison between cleared and non cleared sites to see the effect that land use change has upon chloride balance. | Requires sites on same soils with native and cleared vegetation. Also does not allow comparison of different land use scenarios. | Ian Gordon, Department of Natural Resources, Indooroopilly Sciences Centre, 80 Meiers Road Indooroopilly 4068 Phone (07) 3896 9471<br>Ian.Gordon@dnr.qld.gov.au |
| **PERFECT** | To predict the effects of climate, soil type, crop sequence and fallow management on the water balance, erosion, productivity of cereal growing areas of the subtropics. | Developed as a research tool with an educational version available. | Deals with the water balance, crop productivity and soil erodibility. | Designed for the subtropics. Model has been successfully validated and applied in some semi arid areas but no work has been undertaken in Tasmania. | Dr. Mark Littleboy, NSW Department of Land and Water Conservation, PO Box 189, NSW 2620.<br>Phone (02) 62984022<br>mlittleboy@dlwc.nsw.gov.au |
| **WAVES** | To simulate energy, water, carbon and solute balances of soil-plant-atmosphere system. Used to predict plant growth responses and drainage under different land management options. | Researchers, graduate students. Land managers, planners and extension staff with provision of modelled outputs information. | Generic model not specifically designed for any particular climate region, soil type or vegetation system. | Available vegetation parameters have not been developed for Tasmania. | Warrick Dawes, CSIRO Land and Water, Christian Building, PO Box 1666, Canberra, ACT<br>Phone (02) 62465751<br>warrick.dawes@csiro.au |
| **SWIMv2** | To improve the management of soil water and nutrients to enhance sustainable production systems management. | Researchers, university lecturers and consultants. | Addresses soil water and solute balance issues. | Requires very intensive experimental soil data. | Dr Keith Bristow, CSIRO Land and Water, PMB, PO Aitkenvale, QLD 4814<br>Phone (07) 47538596<br>keith.bristow@csiro.au |
| **APSIM** | Simulates the biophysical aspects of farming systems. Equal emphasis is | A number of interfaces provide access to | Modular framework allows modelling of waterbalance, soil | At this stage access limited by licence agreements. | Details of APSIM and further contact information can be found at |

| | | | | | |
|---|---|---|---|---|---|
| | placed on production activity in relation to management, the fate of the soil resource and losses of water and nutrients beyond the farm. | researchers, farm advisers, agribusiness, land managers and policy analysts. | and plant nutrition, plant yield, economic returns, andmanagement scenarios. Allows configuration by user. | Licensing may be relaxed in future. Requires extensive parameter measurement before use in Tasmania. | http://apsim-help.tag.csiro.au |
| **HYDRUS2D** | The analysis of water flow and solute transport in variably saturated porous media. | Researchers | Able to model movement of salt in the soil in two dimensions. | Does not model interaction of plants and soils and requires extensive training. | http://www.ussl.ars.usda.gov/models/hydrus2d.HTM |
| **SWAGMAN** | Several models specifically developed to determine impacts of management and climate on deep drainage and watertables, on salinisation and yield, and the trade-offs between environmental objectives and profitability. | A number of interfaces provide access to researchers, farm advisers, agribusiness, land managers and policy analysts. | Allows informed decision making within long-term limits of resource availability. Models are simple and adaptable enough to represent essential elements of irrigated production. | Requires extensive parameter measurement before use in Tasmania | Dr Shahbaz Khan, CSIRO Land and Water, Griffith, NSW, 2680<br>Phone (02) 69601500<br>shahbaz.khan@csiro.au |

# APPENDIX 2. THE PARAMETERS USED IN THE WAVES MODEL FOR VEGETATION.

| No. | Parameter | Unit |
|---|---|---|
| 1 | 1 minus albedo of the canopy | - |
| 2 | 1 minus albedo of the soil | - |
| 3 | Rainfall interception coefficient | $m\ d^{-1}LAI^{-1}$ |
| 4 | Light extinction coefficient | - |
| 5 | Maximum carbon assimilation rate | $kg\ C^{-2}\ d^{-1}$ |
| 6 | Slope parameter for the conductance model | - |
| 7 | Maximum plant available soil water potential | m |
| 8 | IRM weighting of water | - |
| 9 | IRM weighting of nutrients | - |
| 10 | Ratio of stomatal to mesophyll conductance | - |
| 11 | Temperature when the growth rate is 1/2 of optimum | °C |
| 12 | Temperature when the growth is optimum | °C |
| 13 | Year day of germination | d |
| 14 | Degree-daylight hours for growth | °C hr |
| 15 | Saturation light intensity | $\mu moles\ m^{-2}\ d^{-1}$ |
| 16 | Maximum rooting depth | m |
| 17 | Specific leaf area | $LAI\ kg\ C^{-1}$ |
| 18 | Leaf respiration coefficient | $kg\ C\ kg\ C^{-1}$ |
| 19 | Stem respiration coefficient | $kg\ C\ kg\ C^{-1}$ |
| 20 | Root respiration coefficient | $kg\ C\ kg\ C^{-1}$ |
| 21 | Leaf mortality rate | Fraction of C $d^{-1}$ |
| 22 | Above-ground partitioning factor | - |
| 23 | Salt sensitivity factor | - |
| 24 | Aerodynamic resistance | $s\ d^{-1}$ |
| 25 | Crop harvest index | - |
| 26 | Crop harvest factor | - |